

## NASA's Space Launch System: Deep-Space Delivery for SmallSats

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### ABSTRACT

Designed for human exploration missions into deep space, NASA's Space Launch System (SLS) represents a new spaceflight infrastructure asset, enabling a wide variety of unique utilization opportunities. While primarily focused on launching the large systems needed for crewed spaceflight beyond Earth orbit, SLS also offers a game-changing capability for the deployment of small satellites to deep-space destinations, beginning with its first flight. Currently, SLS is making rapid progress toward readiness for its first launch in two years, using the initial configuration of the vehicle, which is capable of delivering more than 70 metric tons (t) to Low Earth Orbit (LEO). Planning is underway for smallsat accommodations on future configurations of the vehicle, which will present additional opportunities. This paper will include an overview of the SLS vehicle and its capabilities, including the current status of progress toward first launch. It will also explain the current and future opportunities the vehicle offers for small satellites, including an overview of the CubeSat manifest for Exploration Mission-1 in 2018 and a discussion of future capabilities.

### INTRODUCTION

Designed to deliver the capabilities needed to enable human exploration of deep space, NASA's new Space Launch System rocket is making progress toward its first launch. NASA is making investments to expand the science and exploration capability of the SLS by leveraging excess performance to deploy small satellites. The first launch of SLS, Exploration Mission 1 (EM-1), will include thirteen 6U Cubesat small satellites to be deployed beyond low earth orbit. By providing an Earth-escape trajectory, opportunities are created for the advancement of small satellite subsystems, including deep space communications and in-space propulsion. This SLS capability also creates low-cost options for addressing strategic knowledge gaps and affordable science missions.

Through developing the requirements and integration processes for EM-1, NASA is outlining the framework for the evolved configuration of secondary payloads on SLS Block upgrades. The lessons learned from the EM-1 mission will be applied to processes and products developed for future block upgrades. In the heavy-lift configuration of SLS, payload accommodations will increase for secondary opportunities.

### SLS OVERVIEW AND STATUS

Conceived and designed to enable exploration and discovery in deep space, NASA's Space Launch System (SLS) represents a transformative capability for a wide range of potential missions. (Fig. 1)



**Figure 1: Artist Rendition of Space Launch System**

This exploration-class launch vehicle's primary purpose is to provide the foundational launch capability for human exploration of deep space, propelling humans beyond low Earth orbit (LEO) for the first time in almost half a century. Ultimately, it will support

previously-impossible missions farther into space than ever before, demonstrating new capabilities and ultimately enabling crewed landings on Mars. SLS' performance translates into capabilities that are paradigm-shifting for spacecraft designers and mission planners, enabling architectures and mission profiles not currently possible.

SLS is designed to evolve to deliver greater mass and volume to support different types of missions as human exploration goals demand them. The initial configuration of SLS, known as Block 1, was designed to support initial demonstration of the vehicle's heavy-lift capability, and is making progress toward launch in two years. This configuration, which can deliver greater than 70 metric tons to LEO, will launch NASA's Orion crew vehicle into lunar orbit. For its second flight, SLS will evolve into a more-capable configuration, the Block 1B vehicle, which will increase the vehicle's payload-to-LEO capability to 105 metric tons. The third configuration, Block 2, will be able to deliver 130 metric tons to LEO. The Block 1B and Block 2 vehicles can be configured to carry either the Orion crew vehicle with an additional, co-manifested payload, or to carry a large primary payload in a fairing as large as 10 meters in diameter.

NASA is developing SLS in parallel with two other exploration systems development efforts – the Orion crew vehicle program, managed at NASA's Johnson Space Center in Houston, Texas, and the Ground Systems Development and Operations (GSDO) program, which is converting the facilities at NASA's Kennedy Space Center (KSC) in Florida into a next-generation spaceport capable of supporting launches by multiple types of vehicles.

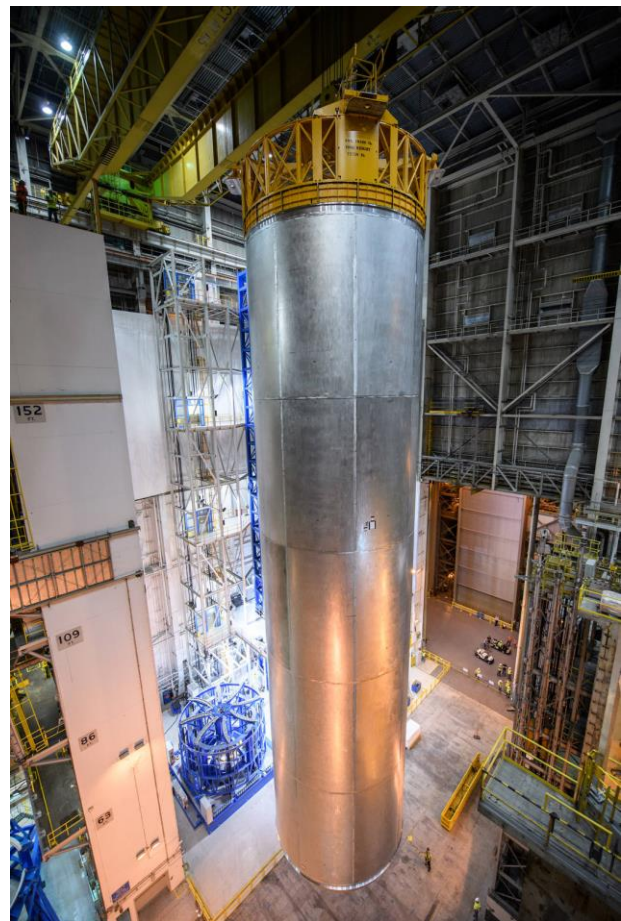
These capabilities are part of a larger NASA strategy of working with commercial partners that will support crew and cargo launches to the International Space Station, while the agency focuses its development efforts on an incremental approach to developing the systems necessary for human exploration beyond Earth orbit and eventually to Mars.

In October 2015, the SLS Program completed its Critical Design Review (CDR), the first time a NASA human-class launch vehicle has reached that milestone since the Shuttle Program almost 40 years ago and the first for an exploration-class vehicle since the Saturn V.

Today, substantial progress has been made toward Exploration Mission-1 (EM-1), the first integrated launch of the SLS rocket with the Orion spacecraft.

### ***Core Stage***

The SLS Core Stage, which stores the liquid oxygen and liquid hydrogen propellant for four liquid engines, represents almost two-thirds of the vehicle's 98-meter height, standing 64 m tall, and has a diameter of 8.4 m, sharing commonality with the space shuttle's external tank in order to enhance compatibility with equipment and facilities at KSC and elsewhere. At Michoud Assembly Facility (MAF), outside New Orleans, Louisiana, the world's largest space vehicle welding tool, the 52m-tall Vertical Assembly Center (VAC), is currently being used by The Boeing Company, core stage prime contractor, to weld barrel sections, rings and domes together to form the test and flight articles of the propellant tanks for the stage. (Fig. 2)



**Figure 2: Production of LH2 tank test article**

Structural test and flight engine sections have completed welding. The test hardware is at MSFC for structural tests. Structural test and flight liquid hydrogen tanks and the flight forward skirt have also completed welding. Progress on the first example of the largest rocket stage in the world has been slowed by

production issues and a tornado which struck MAF in spring 2017.

### ***RS-25 Engines***

The core stage will be powered by four RS-25 engines – which previously served as the Space Shuttle Main Engine (SSME) – taking advantage of 30 years of U.S. experience with high performance liquid oxygen and liquid hydrogen propulsion, as well as an existing U.S. national infrastructure that includes specialized manufacturing and launching facilities. These human-rated engines support the SLS pursuit of safety, with a record of 100 percent mission success for the engines over 135 flights. At the end of the Space Shuttle Program, 16 RS-25 flight engines and two development engines were transferred to the SLS Program and placed in inventory at NASA’s Stennis Space Center in Mississippi, providing enough engines for the first four flights of SLS as well as the SLS engine adaptation program. The engines are managed under a contract with Aerojet Rocketdyne.

Modifications to Stennis Test Stand A-1 to support RS-25 testing were completed in 2014, and testing has been underway since the beginning of 2015 in preparation for flight certification of the SLS configuration of the engine, including recent testing of the flight hardware of a new engine controller unit. (Fig. 3) The testing includes propellant pressure and temperature inlet conditions that will both be higher with SLS than with the shuttle, as well as other SLS-specific performance requirements such as 109 percent thrust versus the shuttle’s 104.5 percent thrust (as well as margin testing to 111 percent in anticipation of future performance increases). Stennis Test Stand B-2 is being refitted for the SLS “green run” – the test firing of the first Core Stage with four RS-25 engines. The test will be the largest liquid-engine test since stage tests of the Saturn V in the 1960s.



**Figure 3: RS-25 Engine Testing**

### ***Solid Rocket Boosters***

The majority of the thrust for the first two minutes of flight will come from a pair of solid rocket boosters (SRB), also of Space Shuttle Program heritage. The SLS is upgrading the boosters from the four-segment version flown on the shuttle to a more-powerful five-segment version. Each booster measures 54 m long and 3.7 m in diameter and is capable of generating up to 3.6 million pounds of thrust, the most powerful flight boosters in the world. Although largely similar to the SRBs used on the space shuttle, this upgraded five-segment SRB includes improvements such as a larger nozzle throat and an environmentally-benign insulation and liner material (asbestos-free).

In June 2016, the SLS configuration of the booster successfully underwent the second of two Qualification Motor tests, and booster hardware is currently being prepared for first flight. (Fig. 4) The tests took place at the Promontory, Utah facility of Orbital ATK, the prime contractor for the boosters. Nine of ten booster motor segments have been cast with propellant at Orbital ATK facilities and two segments are complete and in storage, awaiting shipment to Kennedy Space Center.



**Figure 4: Solid Rocket Booster Testing**

### ***In-Space Propulsion***

In-space propulsion for the Block 1 vehicle will be provided by an Interim Cryogenic Propulsion Stage (ICPS) (Fig. 5). In order to expedite the initial launch of this new U.S. super-heavy-lift launch capability, the decision was made early in the vehicle’s development to leverage the proven Delta Cryogenic Second Stage (DCSS) for SLS in-space propulsion for EM-1, delaying development of a larger upper stage until the vehicle’s core stage was more mature. To provide the necessary power to propel Orion on its EM-1 trajectory, the LH2 tank of the SLS ICPS was stretched 46 centimeters longer than the standard DCSS. The ICPS



is being produced by United Launch Alliance (ULA) in Decatur, Alabama, under contract to Boeing. The ICPS structural test article was shipped to NASA's Marshall Space Flight Center (MSFC) for testing, and the ICPS flight unit has already been shipped to Cape Canaveral Air Force Station in Florida for final processing prior to delivery to adjacent Kennedy Space Center for stacking.

The Block 1 spacecraft/payload elements include not only the ICPS but also two adapters, connecting that stage to the core stage and to the Orion spacecraft. The Launch Vehicle Stage Adapter (LVSA), which connects the core stage with the ICPS, is being produced by Teledyne Brown Engineering of Huntsville, Ala., and is in final welding on-site at Marshall. The Orion Stage Adapter (OSA), which connects the Orion spacecraft with the ICPS, is being produced by Marshall. An OSA produced by the SLS Program flew successfully on the Exploration Flight Test-1 of Orion in December 2014; and the EM-1 flight unit has been welded at Marshall. A stack of test articles for all three elements recently underwent structural testing at Marshall Space Flight Center, qualifying them for flight.



**Figure 5: Interim Cryogenic Propulsion Stage**  
**EVOLUTION PLANS AND PROGRESS**

While the Program's focus is very much on preparation for the first launch in two years, work is already well underway on development for future missions and evolved configurations of the vehicle.

Current plans are for the second flight of SLS with Orion to use the Block 1B configuration of the vehicle, capable of delivering 105 metric tons of payload to LEO (Fig. 6) The Block 1B vehicle will replace the single-engine ICPS with a more-powerful, four-engine, dual-use Exploration Upper Stage (EUS), which will provide both ascent and in-space propulsion. The contract for the EUS has been awarded to Boeing and an agreement has been reached with Aerojet Rocketdyne to provide the stage's RL10-C3 engines. A

Preliminary Design Review for the stage concluded in early 2017, and initial hardware production has begun.



**Figure 6: Block 1B Configuration of SLS**

The change from the 5-meter ICPS to the 8.4-meter EUS means that the LVSA and OSA will be supplanted by a Universal Stage Adapter (USA), which will provide room for a co-manifested payload to fly on an SLS along with Orion. The Universal Stage Adapter (USA) will be managed by NASA's Glenn Research Center in Cleveland, Ohio. Plans currently call for the award of a contract for the USA in summer 2017. Within the USA will be a payload adapter, a demonstrator version of which is currently being built at Marshall.

Other work for Exploration Mission-2 (EM-2) is also currently taking place. Welding for the second core stage has been taking place at Michoud Assembly Facility, and in March 2016, a test-firing of an EM-2 RS-25 engine was performed at Stennis Space Center. Wind tunnel testing is maturing understanding of crew and cargo versions of the Block 1B vehicle.

Work is also currently underway toward making upgrades and affordability enhancements to the RS-25 engines and restarting the production line for the fifth flight of SLS and beyond, after the initial inventory of shuttle RS-25s is expended.

The SLS Program has also conducted initial engineering demonstration and risk reduction work on advanced booster technologies and concepts, preparing for a later upgrade from the shuttle-derived boosters to new boosters that will deliver greater performance. With that upgrade, SLS will reach the fully evolved Block 2 configuration.

## CAPABILITIES

Space Launch System offers substantial benefits in three primary areas, which offer game-changing opportunities for spacecraft designers and mission planners – volume, mass and departure energy.

SLS offers greater volume than any other launch vehicle. Beginning with EM-2, the Universal Stage Adapter will allow a payload to fly with Orion with as much accommodation volume as the current industry-high 5-meter fairing. The Block 1B configuration will also enable the use of an 8.4-m fairing for primary payloads, and the Block 2 vehicle will be able to carry 10m fairings with a volume of up to 1,800 cubic meters, several times greater than any currently available fairing.



**Figure 7: SLS Fairing Options**

For missions to, or staging in, the Earth-moon vicinity, SLS offers unrivaled mass lift capability. The Block 1B configuration of the vehicle, which will be the version available for payloads during most of the 2020s, will be able to lift more than 105 metric tons to LEO and will be able to deliver 41 metric tons to translunar injection (TLI). The crew configuration of the Block 1B vehicle can carry up to an additional 10 tons of payload along with the Orion spacecraft. The Block 2 configuration will increase that performance to more than 130 metric tons to LEO, and at least 45 t to TLI.

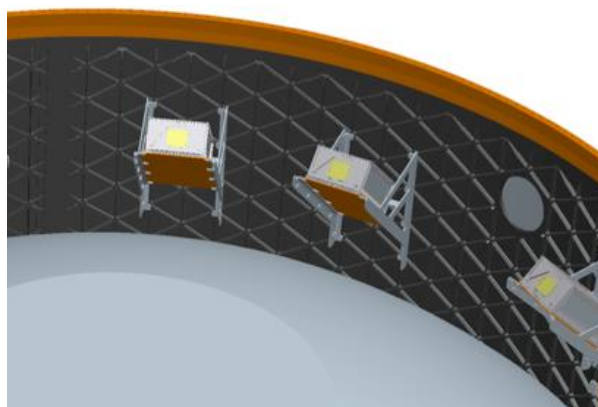
For missions beyond the Earth and moon, SLS offers substantially greater characteristic energy (C3) than contemporary evolved expendable launch vehicles (EELVs). For the missions to the outer planets, for

example, this can enable a larger science package, reduced transit times, or both.

These primary benefits make possible a variety of secondary benefits. For example, greater payload volume can decrease the need for miniaturization “origami” deployments, thus simplifying the spacecraft design cycle, as well as complexity and risk. Reducing transit time by enabling a direct trajectory without gravitational assists reduces mission risk and operational cost, and can eliminate the need to design for inner-solar system conditions.

## SMALLSAT UTILIZATION

While the most obvious mission profiles to benefit from SLS are those with requirements beyond the performance of current launch vehicles, SLS will also offer unique opportunities for smaller experiments in the form of secondary payload berths. Thirteen secondary payload locations will be available in the Orion-to-Stage Adapter in the initial SLS configuration, allowing payload deployment following Orion separation. (A total of fourteen brackets will be installed, allowing for thirteen payload locations. The final location will be used for mounting an avionics unit, which will include a battery and sequencer for executing the mission deployment sequence.) The deployment berths are sized for 6U CubeSats, and on EM-1 the spacecraft will be deployed into cislunar space following Orion separate from the SLS Interim Cryogenic Propulsion Stage. Payloads in 6U class will be limited to 14 kg maximum mass.



**Figure 8: SLS CubeSat Accommodations**

The avionics unit will interface with each deployer through cables mounted in the OSA. Payloads will remain powered off until the sequencer transmits the deployment signal to each dispenser, and the payload is released. Payloads will exit the dispenser at an approximate rate of 1.2 m/sec, with deployments separated by a minimum of 5 seconds. No ot

The SLS Program will perform all mission and payload integration for the baseline vehicle manifest. The mission integration process defined in this section has been developed to ensure safety and mission success, while reducing the amount of data required from the payload developers.

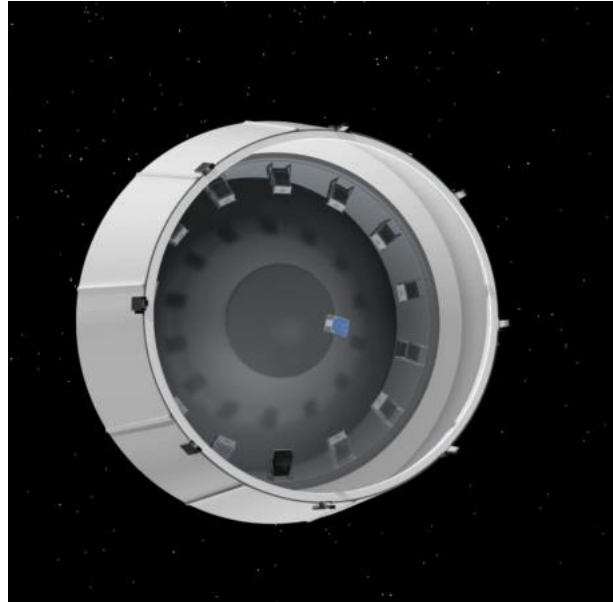
The integration process is designed to support the payload requirements as well as the requirements of the launch vehicle and ground systems. The typical integration process encompasses the entire cycle of payload integration activities including analytical and physical integration.

Payloads will be turned over to GSDO fully integrated in their deployer, ready for installation in the OSA at approximately L-6 months. GSDO will install the integrated deployers onto the OSA brackets and mate all required connections for deployment signals. Payloads will not be accessible once stacking operations begin. For EM-1, additional tests and pad stay time is required to fully check out the vehicle configuration. Due to this “first flight” test activity, the vehicle will remain at the launch pad for up to two months, which will increase payload exposure to documented natural environments. Payload should consider this additional time into their design requirements for materials selection and battery life.

Secondary payloads on SLS will remain powered off during the ascent phase of the launch vehicle, through separation of the Orion spacecraft. Once separation is confirmed, the ICPS will send a discrete signal to the SPDS avionics to activate. The schedule for deployments will be loaded as a skit prior to vehicle stacking. No real-time commanding or telemetry is available; therefore payloads will be deployed automatically through the pre-determined mission timeline sequence.

Payloads will have opportunity to deploy beginning after the ICPS disposal sequence is complete (approximately T+4 hours) up to 10 days from launch. All deployments will be completed before avionics batteries are expended. (Fig. 9)

Once deployed, payloads will be required to wait 15 seconds before deploying antennas, solar panels, sails, etc. to ensure adequate clearance from ICPS. Payload communications following deployment will be the responsibility of the payload project, with no resources being provided by SLS.



**Figure 9: Deployment of EM-1 CubeSat**

#### *EM-1 CubeSats*

CubeSat payloads on EM-1 will include both NASA research experiments and spacecraft developed by industry, international and potentially academia partners. The Human Exploration and Operations Mission Directorate (HEOMD) Advanced Exploration Systems (AES) Division was allocated five payload opportunities on the EM-1 mission. AES selected the first three payloads to fly on EM-1 at the same time the capability for accommodating Secondary Payloads on the SLS was being developed.

Near Earth Asteroid (NEA) Scout is a 6U cubesat designed to rendezvous and characterize a candidate NEA. A solar sail, another innovation to be demonstrated in the cubesat class, will provide propulsion.

Lunar Flashlight is the second AES payload planned for manifest on EM-1. It will use a green propellant system and will search for potential ice deposits in the Moon's permanently shadowed craters. Pulsed lasers will be used to illuminate the surface. Surface reflection will be measured by a spectrometer to distinguish water ices from regolith.

The third payload being developed by AES is BioSentinel. The payload is a yeast radiation biosensor, planned to measure the effects of space radiation on Deoxyribonucleic acid (DNA). This will be accomplished by entering into a heliocentric orbit, outside of the Van Allen belts to expose the payload to a deep space radiation environment.

Two additional payloads were selected for the EM-1 mission by AES from the Next Space Technologies for Exploration Partnerships (NextSTEP) Broad Agency Announcement (BAA). The payloads selected are Lunar Icecube, a collaboration with Moorehead State University, and Skyfire, a partnership with Lockheed Martin. Lunar Icecube will prospect for water in ice, liquid, and vapor forms as well as other lunar volatiles from a low-perigee, highly inclined lunar orbit using a compact Infrared spectrometer. Skyfire is a technology demonstration mission that will perform a lunar flyby, collecting spectroscopy, and thermography data to address questions related to surface characterization, remote sensing, and site selection.

NASA's Space Technology Mission Directorate (STMD) was allocated three payload opportunities on the EM-1 mission. NASA's STMD is innovating, developing, testing, and flying hardware for use in NASA's future missions through the Centennial Challenges Program. The Centennial Challenges Program is NASA's flagship program for technology prize competitions ([www.nasa.gov/challenges](http://www.nasa.gov/challenges)). The program directly engages the public, academia, and industry in open prize competitions to stimulate innovation in technologies that have benefit to NASA and the nation. STMD has released the CubeSat Lunar Challenge to foster innovations in small spacecraft propulsion and communications. There are two concurrent In-Space Competitions, the Lunar Derby and the Deep Space Derby. In the lunar Derby, there are prizes awarded for successfully achieving lunar orbit, downlinking the largest volume of error-free data and surviving the longest. In the Deep Space Derby (> 4 million km), there are prizes awarded for farthest data transmission distance, largest volume of error-free data and longest duration of operability. Potential candidates for the three STMD opportunities on the EM-1 mission competed in a series of four Ground Tournaments before final selection is made. (WILL ADD WINNERS AFTER ANNOUNCEMENT THURSDAY)

The NASA Science Mission Directorate (SMD) was allocated two payload opportunities on the EM-1 mission. The NASA SMD issued an amendment to its annual Announcement of Opportunity (AO) in the Research Opportunities in Space and Earth Sciences-2014 (ROSES-2014) Solicitation NNH14ZDA001N-HTIDS Heliophysics Technology and Instrument Development for Science. Within this Amendment was the request for Cubesat proposals specific to the Exploration Mission 1 launch opportunity focusing on the Heliophysics science enabled through the unique deployment location and trajectory afforded through the planned EM-1 mission. The Cubesat Mission to Study Solar Particles (CuSP) payload was selected under this

AO. CuSP will study the sources and acceleration mechanisms of solar and IP particles in near-Earth orbit, support space weather research by determining proton radiation levels during Solar Energetic Particle (SEP) events and identifying suprathermal properties that could help predict geomagnetic storms. A Small Innovative Missions for Planetary Exploration (SIMPLEx) NASA Research Announcement (NRA) was also released as part of the ROSES-2014 AO. The LunaH-Map payload was selected from this NRA. The LunaH-Map objectives are to understand the quantity of H-bearing materials in lunar cold traps (~10 km), determine the concentration of H-bearing materials with 1m depth, and constrain the vertical distribution of H-bearing materials.

The final three payload opportunities for the EM-1 mission were allocated for NASA's international space agency counterparts. The flight opportunities are intended to benefit the international space agency and NASA as well as further the collective space exploration goals. A joint process with NASA and the international partners was employed to review, evaluate, and recommend the payloads to fly on EM-1. From that joint process three payloads were chosen: Omotenashi, (formerly SLS Launched Innovative Mission [SLSLIM]), ArgoMoon, and EQUilibrIUm Lunar-Earth point 6U Spacecraft (EQUULEUS). ArgoMoon is sponsored by ESA/ASI and will fly-along with the ICPS on its disposal trajectory. The primary objectives are to perform proximity operations with the ICPS post-disposal, take external imagery of engineering and historical significance, and perform an optical communications demonstration. The EQUULEUS spacecraft sponsored by JAXA will fly to a libration orbit around the Earth-Moon L2 point and demonstrate trajectory control techniques within the Sun-Earth-Moon region for the first time by a nano spacecraft. The mission will also contribute to the future human exploration scenario by understanding the radiation environment in geospace and deep space, characterizing the flux of impacting meteors on the far side of the moon, and demonstrating the future deep space exploration scenario using the "deep space port" at Lagrange points. The OMOTENASHI mission sponsored by JAXA will land the smallest lunar lander to date on the lunar surface to demonstrate the feasibility of the hardware for distributed cooperative exploration system. Small landers will enable multi-point exploration, which is complimentary with large-scale human exploration. Once on the lunar surface, the OMOTENASHI spacecraft will observe the radiation and soil environments of the lunar surface by active radiation measurements and soil shear measurements.

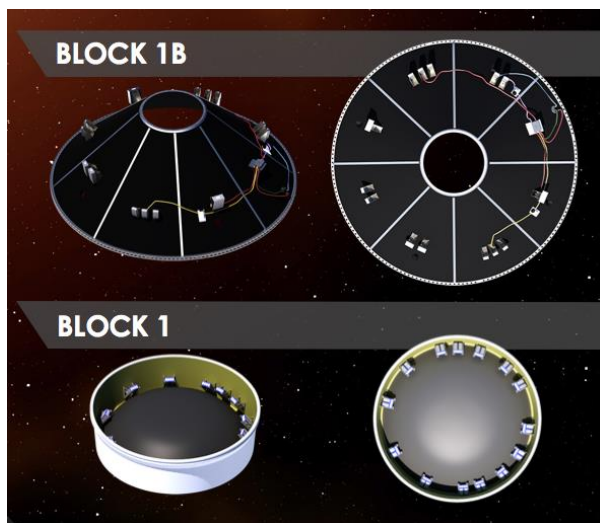


### ***Future Opportunities***

After EM-1, SLS will evolve from the 70 t Block 1 configuration to the 105 t Block 1B configuration. That configuration of the rocket will replace the one-engine ICPS in-space stage with the four-engine EUS upper stage, and, as a result, replace both the LVSA and the OSA, where the EM-1 CubeSat payloads will be mounted, with the new Universal Stage Adapter (USA). The USA will allow the rocket to carry large co-manifested payloads along with the Orion spacecraft, and these payloads will be mounted within the USA on a Payload Adapter. (These hardware elements will also be part of the 130 t Block 2 configuration of the vehicle, so planning for secondary payload accommodations on the Block 1B vehicle will be relevant to Block 2 as well.)

Current plans are for this Payload Adapter to carry smallsat secondary payloads. In this arrangement, SLS would be able to carry both larger CubeSats and more of them. The Payload Adapter would have eight areas for mounting secondary payload hardware. As on the Block 1 configuration, one of those areas would be used for an avionics unit. Each of the remaining areas could be used to carry either one 27U CubeSat, two 12U CubeSats, or three 6U CubeSats, in any combination. It could, for example, carry seven 27U CubeSats or 21 6U CubeSats or two 27U, six 12U and six 6U payloads. (Fig. 10)

and exploration. The capability to deploy small satellites allows SLS to utilize excess capability on the planned exploration missions. With the planned mission trajectories, small satellite payload developers will have an opportunity to operate in deep space, a capability not realized to this point. As the SLS vehicle evolves its configuration and becomes more capable, the opportunities for Secondary Payloads of different types and sizes will increase.



**Figure 10: Block 1 v 1B Accommodations**

Possibilities are still being evaluated for enabling even larger smallsats or adding more berths in the future.

### **CONCLUSION**

NASA's Space Launch System (SLS) will provide unprecedented capability to further advances in science